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Abstract

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QUALITATIVE ANALYSIS OF THE USE OF BUILDING PERFORMANCE SIMULATION IN THE AUSTRALIAN RETROFITTING INDUSTRY

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ABSTRACT

Building Performance Simulation (BPS) is a key tool in the existing building energy retrofit optimization process, allowing a user to predict energy savings from upgrades. However, little research exists into how BPS is being employed in commercial settings. This paper reports on a qualitative study which examined the use of BPS in the Australian commercial building retrofitting industry. Qualitative analysis of the interview data revealed numerous challenges for BPS users, primarily related to the lack of reliable, accessible data regarding building operations and energy use in Australia. The poor data availability encouraged the use of simulation to inform decisions, but required the modeller to use assumptions and heuristics to develop the model. This in turn necessitated a reliance on the expert knowledge of the simulation user, and made the interrogation of a building model by a third party very difficult.

INTRODUCTION

Building performance simulation (BPS) is a key tool within the Australian building design industry for predicting energy savings in the retrofit optimization process (Ma *et al.*, 2012). However, there is a well reported gap between predicted and actual energy consumption (Bordass *et al.*, 2004; Torcellini *et al.*, 2004), one explanation of which is the use of inaccurate simulation assumptions (Menezes *et al.*, 2011; Simm *et al.*, 2011). BPS practitioners are often limited by a lack of access to detailed data on specific building construction and operation characteristics. Determining these characteristics can be a difficult, disruptive and expensive exercise. As a result, modellers must rely on assumptions or default values regarding occupant behaviour and hard-to-measure building characteristics as inputs to building performance simulation programs (Hampton, 2011). At the same time, there is a lack of reliable, publicly available data upon which to base assumptions for Australian office building characteristics.

The research described in this paper aimed to understand how BPS practitioners were using simulation tools in the existing building retrofitting industry, including how they were dealing with issues of uncertainty in simulation inputs and outputs.

RESEARCH METHOD

Interviewees

Prospective participants invited to participate in this research project were experts in the field of building energy retrofitting or building simulation, with experience in commercial building energy retrofitting. They were identified via existing networks established by staff and students of the Sustainable Buildings Research Centre (SBRC). Participants were asked about their understanding of the decision making process used to assess building retrofit strategies, including economic, technical, and attitudinal barriers and incentives. Building simulation users in commercial consulting companies were also asked about modelling practices and data sources. A semi-structured approach was appropriate, as it allowed the participant to direct the interview towards areas they viewed as important, rather than the interviewer setting the agenda.

An invitation to participate in the interview process was distributed to 18 identified experts, semi-structured interview were undertaken with 12 participants. Interviews ranged in length from 17 to 55 minutes. Eight consultants, two building managers, and two government representatives were interviewed. Pseudonyms (e.g. Consultant A)were used to provide a level of anonymity to participants.

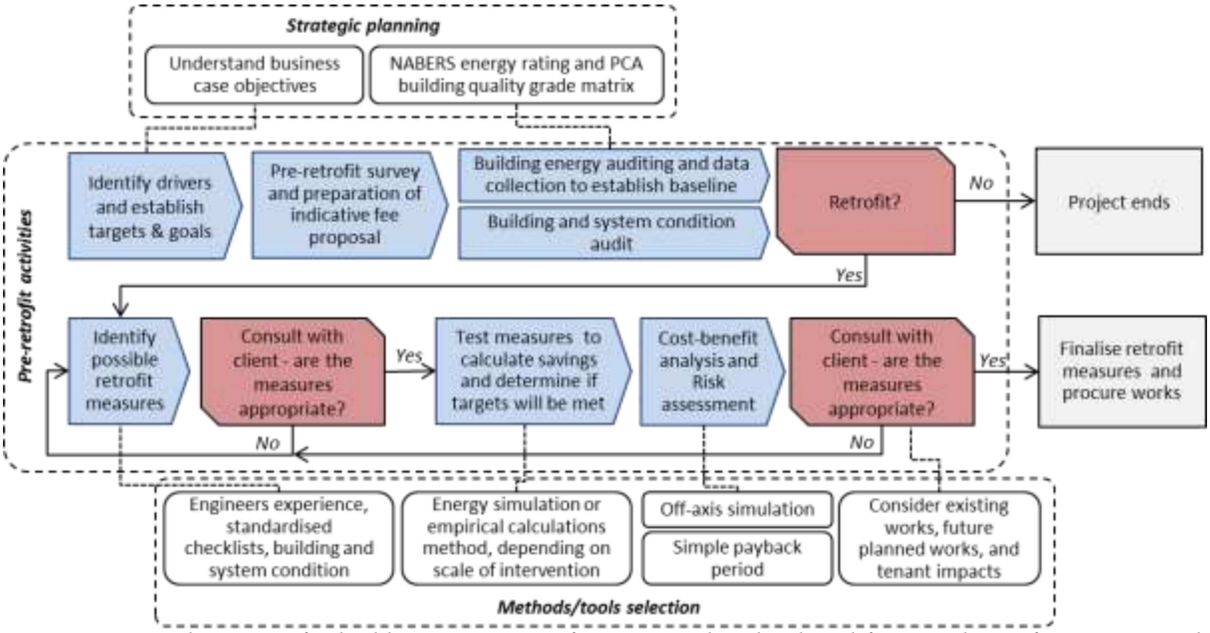

Figure 1 'Typical' process for building energy retrofits in Australia, developed from analysis of interviews with eight commercial retrofitting consultants.

Qualitative analysis

The approach to the qualitative analysis was drawn from Waitt (2010), Creswell (2014), and Saldaña (2009).The interviews were recorded and transcribed, and then reviewed against the audio to ensure accuracy. The analysis considered all the data to identify common issues and emergent themes across sources. Initially, all transcriptions were read, and clear or obvious themes were identified or noted in the margins. A fresh copy of the transcription was then re-read in detail, and emergent themes were identified and coded. In qualitative research a code refers to 'a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of … data'(Saldaña, 2009). Coding is therefore the categorisation and linking of data to ideas. QSR International's NVivo 10 qualitative data analysis software package (QSR International Pty Ltd 2012) was used to facilitate this coding process. Consideration was given to maintaining reflexivity (i.e. suspending pre-existing categories and responding to the text), and absorbing oneself in the texts. Comparison was made between responses from different professional groups, locations, and experiences. The responses were considered in relation to the relevant literature.

RESULTS ANALYSIS

The following sections present several key themes which emerged during the coding of the interview transcripts. A discussion of the interrelation of the themes, and the broader context is included as the discussion.

The Generic Building Energy Retrofitting Problem: a Process Review

Each interviewee was asked to explain their understanding of the building energy retrofitting process, from start to finish. The interviewer prompted the interviewee to cover issues regarding stakeholders, drivers and post retrofit involvement when appropriate. The responses were compared to the systematic approach to building energy retrofitting proposed by Ma *et al.* (2012) (referred to as the 'Systematic Approach' in this paper). The Systematic Approach was developed following an extensive literature review, and has been widely cited as a best-practice approach (Dall'O' & Sarto, 2013; Volvačiovas *et al.*, 2013) The Systematic Approach, displayed in Figure 2 with revisions highlighted, presented a comprehensive method for 'proper selection and identification of the best retrofit options for existing buildings'.

There was strong agreement among the interviewed consultants regarding the typical process that is followed for a building energy retrofit project. Differences between the views of individual consultants could be accounted for given the different business models of their companies, i.e. whether a company managed the practical implementation of retrofit works or simply provided the expertise to identify optimal upgrade strategies. The typical process distilled from the analysis of the interviews is shown in Figure 1. Note that many consultants pointed out that the process varied considerably depending on the specifics of the project. However, all respondents were able to outline what they described as a 'typical' retrofit process, which aligned closely with the process outlined in Figure 2, or with the major elements thereof. There are several

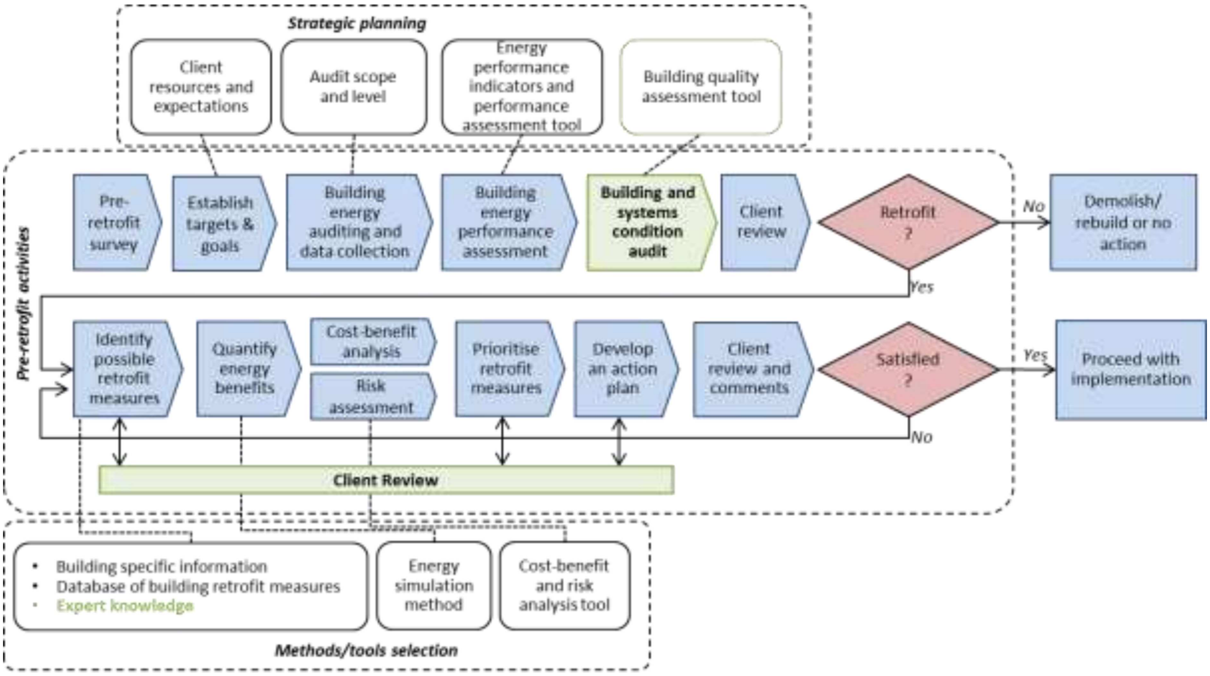

Figure 2 Revised Systematic Approach to sustainable building retrofits, incorporating insights from Australian expert interviewees (changes compared to Fig. 1 highlighted in green).

key differences between the Systematic Approach and the 'Generic Process' identified as a result of the interviews with stakeholders. These differences were both practices that were not included in the Systematic Approach, and some represented possible shortcomings in the actual practice in industry.

The Systematic Approach did not incorporate a condition audit of the existing building and systems. A condition audit of the building systems includes the identification of the current condition and expected remaining life of existing components, and nominates the components that should be replaced as part of a comprehensive refurbishment. Assessing a building's condition against the Property Council of Australia's (PCA) Office Building Quality Matrix (PCA, 2011) may be important in the early stages of a retrofit project in the Australian context. Understanding the current quality and condition of a building allows the owner to make targeted improvements that will improve a building's quality rating. Office quality, as assessed by the PCA matrix, has an influence on rental returns, capital valuation, and tenant attraction (Wilkinson, 2011).

The importance of regular client review during the development of retrofit options and the selection of the optimal retrofit strategy was highlighted repeatedly by the interviewees. Whilst the Systematic Approach incorporated client review at the beginning and end of the retrofit measure identification process, the interviewees' responses suggested greater client involvement is appropriate. The client and building management team will generally have a deeper understanding of the building and systems than the consultant (including the manner in which the building is operated) and this is an important source of information when developing retrofit strategies. Consultant E warned it is easy to come up with theoretical recommendations, which the owners will instantly recognise as unworkable. The retrofit process is not completely rational, as will be discussed later, and often the subjective views of the client may influence the particular retrofit strategies that they are prepared to consider. As identified by Consultant F, involving the client heavily in the decision making process is essential, 'so we don't spend a lot of time pursuing something that they're fundamentally uninterested in'.

Finally, the Systematic Approach suggested that the identification of possible retrofit options is informed by building-specific information and a database of building retrofit measures. The results from the present interviews analysis showed that the generation of possible strategies is grounded in the expert knowledge and experience of the consultant.

Shortcomings of the retrofitting process as practiced in industry, identified through comparison with the Systematic Approach, included a simplistic approach to risk assessment, simplistic cost-benefit analysis, and a scarcity of post-occupancy evaluation studies. In the interviews the consultants often identified these shortcomings as a structural issue, i.e. the benefits of incorporating the additional assessments are known but it is difficult to convince clients to incorporate them into the contract of engagement.

Risk assessment in building energy retrofitting primarily relates to evaluation of the uncertainty in energy savings predictions. Ma *et al.* (2012). identified probability-based risk assessment methods as the most commonly employed methods in their reviewed literature. Risk assessment in the industry was generally limited to off-axis studies during building simulation. Off-axis studies, also known as differential sensitivity analyses, involve varying certain parameters in an energy model away from the expected value to determine the system sensitivity to individual inputs. The consultants who discussed risk assessment raised it in the context of the National Australian Built Environment Rating System (NABERS) energy modelling requirements for commitment agreements (NABERS, 2011). NABERS is an important energy rating scheme for commercial offices in Australia based on operational data. An off-axis study that includes variation of at least four factors is required for compliance with the NABERS program.

Similarly, cost-benefit analyses employed by the consultants interviewed in the present study were generally limited to simple payback period calculations. Cost-optimal retrofit selection can be impacted by the economic metric used (Remer & Nieto, 1995), and more comprehensive methods than simple payback are recommended (Menassa, 2011). Consultant C spoke about this issue:

Some clients are also asking for ROI and NPV using discounting, so more whole life value analyses [than simple payback period]… but more often than not it's based on simple payback calculations, it does not take into account service life, repairs, maintenance. It's a pretty crude decision making criteria.

A Revised Systematic Approach for sustainable building retrofits, built on the Systematic Approach of Ma *et al. (*2012) and incorporating the results and insights from the present interview analysis was presented in Figure 2, with the suggested improvements highlighted.

Drivers for Retrofit Activity and Building Performance Simulation

A particular objective in conducting the interviews was to identify the drivers of building retrofit activity in Australia, and the drivers for consultants to use Building Performance Simulation (BPS) in the process. Many drivers are contextual and the bulk of the interview data was related to New South Wales (NSW) and the Australian Capital Territory (ACT) jurisdictions. However, the responses were generally applicable Australia-wide, as the experience of the consultants covered many of the national capital city markets. Similar issues are likely to exist internationally.

Two related themes, market pressure and tenant expectations, were repeatedly identified by the interviewees as drivers leading building owners to engage with ESD consultants. Fundamentally, financial considerations were the key driver for commercial building retrofit activity. However, financial considerations were mostly spoken of in the context of attracting and retaining tenants, rather than in terms of energy cost savings. There was a recognition that the primary business concern of a commercial building owner is generally to realize higher rental returns and increased capital value (IPD 2010; Newell *et al.* 2011). Consultant D considered the utility bill driver to be, 'not usually a great big driver, but often a driver', while the role of tenant attraction was identified by others as a major driver. The importance of providing buildings that tenants want, which is the core business of owners, was repeatedly identified as a crucial consideration. For example, Government Administrator A: 'Where they [building owners] do invest, they tend to be investing in upgrades that attract tenants, so that's lighting, carpet, paint, fit-outs, and those sorts of things'.

Numerous factors, both national and local in scope, create market pressure. Commercial Building Disclosure (CBD) legislation (requiring disclosure of the energy rating of a building when more than 2000 m^2 of space is advertised for sale or lease) is generally accepted to have created greater transparency in the industry across Australia, which in turn has provided incentives for owners of lower-performing buildings to upgrade. Similarly, expansion of high quality building stock creates improved market conditions for tenants, meaning building owners have to compete more strongly and improve their own offerings. In the context of this improved market for tenants, tenant expectations become a prominent driver for building upgrades. Again, Consultant G:

We've gone from a world where buildings are built for profit …and tenants would come and fit in them … to a world where buildings are being built for tenants. …to attract those tenants for a seven-year lease, you have to make your offer a bit more attractive. So I think that's driving it [building energy retrofitting activity] considerably.

Tenant expectations relate to various building attributes; the most common attributes identified in the interviews were PCA quality grade and NABERS ratings. These two measures are somewhat intertwined as PCA A-grade requires a NABERS rating higher than 3.5 stars, and Premium grade requires a rating higher than 4 stars. As Building Manager B related, for his project, 'The driver, was always NABERS. … everything we wanted to achieve through NABERS, it assisted us to achieve the A-grade rating we wanted.' Consultant C saw tenant expectations as common driver:

… NABERS rating for marketability [is an important driver], particularly to either retain existing tenants, attract new tenants, or reposition the building as a PCA B or A grade. The PCA guide to office building quality is another driver, connected to that trigger point of I want to either keep my existing tenants or I've got a big vacancy and I want to attract new tenants.

A final driver, which has not received much attention in the literature, is the role of human subjectivity in driving priorities in decision making. The decision to upgrade a building is generally not entirely rational, as there are numerous restrictions on the ability to make rational decisions, such as information availability, time restrictions etc. The decision makers are also affected by personal values and priorities. As Consultant D observed, 'the drivers of … [building energy retrofitting activity are] far more related to people who are passionate about a building [than economic drivers]'. One consultant saw the industry as currently reliant on 'educated, interested, enlightened' clients driving improvement works. This human influence is very difficult to characterise, but it is an important factor to be aware of. Consultant D stated:

…usually the decision to retrofit is … subjective rather than objective. It's nowhere near as objective as you'd like it to be.

The Role of Building Performance Simulation in Retrofit Optimization

Many of the interviews included a focus on how the interviewees used BPS in the retrofitting process. Two tiers of processes were identified that were linked to the targets/objectives of the building owners. For building owners with lower targets, decisions would generally be made on the recommendations of a Type 2 audit (standard investigation), for owners with higher aspirations a Type 3 audit (detailed investigation) and BPS would be used.

For projects of sufficient scale to facilitate a BPS, there were several drivers for using simulation. These were seen to fall into three categories: compliance simulation, 'proving-up', and design/optimisation. Compliance incorporates BPS undertaken specifically to satisfy the requirements of a program or legislation. This type of simulation was mentioned by the majority of consultants, though not generally discussed in detail. Consultants A and B, from the same company, stated that compliance was the major driver for BPS. It is likely that this is related to the company's business model.

The second category of simulation was that for the purpose of 'proving up', where the simulation is undertaken to 'prove' that a particular upgrade strategy will result in a specific target being achieved. In many cases the target would have been achieving accreditation in one or more of the compliance schemes, for instance achieving a 5 Star NABERS rating. Another target of a proving-up strategy may have been sizing photovoltaic arrays to achieve net-zero energy. The crucial distinction between this type of simulation and simulation for design or optimisation is that the retrofit strategy has been decided, and BPS was used to ensure that the strategy would achieve the targets. 'The tool validates your answer, and … proves up the strategy that you're putting forward.'

Use of BPS as a design tool to compare different retrofit strategies was identified by several consultants, although Consultant D was the only participant for whom it was the main driver for simulation. For him 'the main driver [for undertaking BPS] is discovering for ourselves what is the right thing to do'. This is in contrast to Consultant F, who had, 'made most of the decisions by the time we're doing the modelling, and the question is really, so we do all this stuff do we get to where we want to be?' Although he saw 'analytical enquiry rather than doing things by gut feel is becoming more prevalent.'

Use of Assumed Inputs in Building Performance Simulation

In analysing discussions on the information used as inputs to BPS models, two intertwined themes emerged which help us understand the uncertainty in BPS of existing buildings. They were: i) the depth of investigations into building and systems undertaken by the consultant, and ii) the use and source of assumptions for unknown inputs. The problem for many consultants is that it is difficult to get a client to pay for the collection of detailed performance data. Collection of data can also be disruptive to the operation of the building, particularly for tenancy-related information: 'It's very difficult to get the data, because … it interferes with the operation of the tenant. They don't really want you there.'

Given the difficulty in accessing accurate information, the interviews investigated how the consultants dealt with uncertain inputs, generally for tenancy and occupancy loads. This was often related to the drivers for simulations to be completed. For compliance simulations assumed input values were generally driven by the requirements of the scheme, for instance, using 'the NABERS default profiles for lighting and computers left on'. For many consultants the NABERS defaults were commonly used for non-compliance simulation to represent unknown tenancies in a base building model. Consultant F did not view this as an issue:

'The NABERS defaults are mildly pessimistic about operating patterns, so they're not a bad sort of position, given that you're trying to prove up a base building performance.'

When simulating tenancies for whole building or tenancy assessments, the issue becomes more important, Consultant F saw it as 'a real problem in the tenancy area, because basically you could derive a result from your assumptions.' Lack of accurate data, and the disruptive nature of gaining information about tenant behaviours meant 'the detail [regarding tenant behaviour in BPS]… it's a lot of assumptions, because we've got absolutely no … idea at all.' The issue, as seen by Consultant B, was:

The information on older building stock is not there, so you end up basing your model on so many assumptions that whatever results you get at the end are not results you can hang your hat on.

An issue with the widespread use of these simple protocols, to represent an input, which can 'vary wildly', was recognised by Consultant D:

[NABERS and similar assumption sources] are fairly well-accepted across the board, and usually when models get peer-reviewed, they always ask those questions. You can say, 'Well, model it to the NABERS protocol.' Not necessarily assuming that that is correct, but it is an industry standard

Universally, the consultants disclosed and discussed the assumption used in the BPS in their dealings with the client. The reason given for this was most often legal protection rather to improve the accuracy of assumption. Many respondents identified the client reaction as a variation on 'you're the professional, just give us the answer'. This response from the client is reasonable, but it relates to another issue identified by many of the respondents, the difficulty in distinguishing between high and low quality consultancies in the BPS field. Essentially a client is relying on a consultant to make reasonable assumptions about a building, in a situation where it is very difficult to differentiate between consultants. Consultant D related a situation where:

a client actually appointed two engineers to model the same building, and they had quite different results, even with very similar outputs [sic], and they engaged in a battle over it. And the main outcome of that was, the client couldn't necessarily decide who was high or low quality

The comparison between 'gut-feel' decisions rooted in experience and expert knowledge, and 'more analytical enquiry' or model-based decision making is an important issue for BPS users. Understanding building systems and operations is a complex task that requires training and experience, as does representing buildings systems and operations accurately in BPS. It is difficult for consultants to balance these competing needs for employee training and development in a commercial environment. Consultant F talked at length about the issue:

The logical thing with a simulation that burns up a lot of hours, is that people [senior managers] put relatively inexperienced people onto doing simulation, … because he [the simulation user] spends so much time behind a computer, he has by far less practical experience looking at real buildings and how real things work than … our general engineering staff. But then, our general engineering staff wouldn't know what to do with a simulation if it ran them over in the middle of the road.

This practice could reasonably be expected to lead to uncertainty in the simulation outcomes due to modeller error, particularly in data interpretation and use of appropriate heuristics and assumptions. The converse situation was also identified, where the simulation user may pre-empt the result of the simulation to match their expectation. As identified previously, simulation is often used to prove-up a previously designed retrofit solution, and if the results are not as expected by an experienced consultant, there is a temptation to force the model to match expected outcomes. This was an issue identified by Consultant D:

The risk is – and this happens often – that you end up playing with it [the model] until you get the answer you expect it should be, and that's the opposite of what modelling should be.

Commercial Pressures in Building Performance Simulation

The previous section relates to a separate theme which emerged during coding of the interviews; the effect of commercial pressures on simulation accuracy. In many cases the respondents were aware that certain aspects in their retrofit decision making process may not be optimal, but felt constrained by the needs of running a viable business. This issue surfaced during the interviews in many ways.

Whilst recognising that it is logical to use junior staff for simulation (a practise he employed), Consultant F recognised:

There will always be some really bad simulations out there, because we still have a situation where somebody's first simulation is presented as a commercial deliverable, and that's going to be a problem.

For other respondents the issue was discussed in terms of not being able to get the client to pay for work they saw as desirable. For instance, the need to rationalize the investigative stage of the retrofit process to expedite the designing process and minimise costs. Consultant E described a complex upgrade project for which BPS may have been beneficial but was not employed:

…a simulation would be really helpful, but the challenge with simulation is, it's a pretty expensive exercise to undertake, so there was no way, within the constraints of our budget, that we were ever going to engage anybody to be able to do that

Consultant C expressed frustration at what he saw as unfair financial criteria being applied to energy efficiency measures by clients, restricting the scope of projects. He explained:

No building owner ever asks what the payback is on a bathroom refit… It's almost an unfair evaluation criteria applied only to energy upgrades, whereas a lot of other things are just done for prestige, marketability.

The potential for continuing improvement was also somewhat hindered by commercial realities, particularly competitiveness. Peer-review of building models was identified as a useful learning process for several consultants. Peer-review of building energy models was discussed in detail with Consultant D, who saw the many potential gains to be made through increased collaboration. Commercial consideration created some barriers to this though. He explained: ‘the hard part is, obviously, a lot of the people available for peer-review are in competitive organisations – so, not such a straightforward thing.’ He continued:

It’s hard, though, because there’s some people you can’t work with very easily because they don’t want to give up their models. Understandably, because a lot of them are full of little short-cuts that they had to take or whatever, and they don’t want to be pulled up on it

DISCUSSION

Through the qualitative analysis of the interview data numerous considerations relating to the use of BPS in Australia were identified. The issues centre on a lack of reliable, accessible data regarding building energy use and building operation in Australia. This lack of data encourages the use of simulation to inform decisions, but requires the modeller to use a lot of assumptions, and heuristics to develop the model. This makes the interrogation of a BPS model very difficult, and necessitates reliance on the expert knowledge of the simulation user. However, at present there are no well-recognised accreditation processes for energy modellers in Australia, and due to commercial pressures, many companies rely on inexperience simulation users. The interview with the Consultant H, who offered EPC’s on the basis of BPS predictions, illustrated that BPS can be used to accurately represent a building and system, and thereby accurately predict the energy savings from a given upgrade strategy. However, the depth of the data collection exercise that was involved in developing and validating these detailed models is cost prohibitive for most commercial modelling engagements. The accuracy and reliability of BPS results from commercial engagements is therefore reliant on the consultant’s judgement of the relative importance of inputs. The interpretive position of the modeller is shown in Figure 3.

The modelling process depicted in Figure 3 is an expert system, requiring significant experience and understanding of a complex system. The practice, identified by Consultant F, of using inexperienced staff to run the labour intensive modelling software is therefore problematic. The use of peer-review and quality assurance techniques can help avoid many issues, however the nature of BPS programs makes error checking itself a challenging task. The difficulty in determining accurate models becomes important for any scheme in which predictions of savings are tied to a financial reward. Relying on predictions from BPS to assess competing bids may incentivise the over-estimation of energy savings, with the understanding that the complexity of prediction and M&V of energy savings will make compliance difficult. A possible improvement is the development and use of a standardised, evidence-based modelling protocol, supported and updated from regular data collection exercises, similar to ASHRAE 90.1 (ASHRAE, 2013). However, a significant data collection exercise would be needed before this resource could be created for Australia.

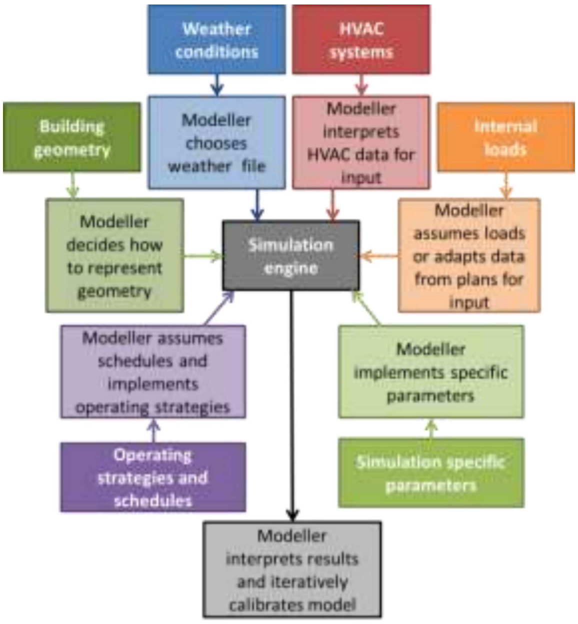

Figure 3 The interpretive role of the modeller in the simulation process, as visualised by Berkeley (2013)

The above issue is compounded by the lack of a universally recognised accreditation scheme for energy modelling professionals in Australia. It is recognised that it is difficult educate people to be good modellers due to the complex nature of the understanding required. Testing this understanding is also difficult. In the USA, ASHRAE successfully administer the Building Energy Modelling Professional certification, which tests and registers professionals who have shown the necessary knowledge to model a commercial building accurately. In Australia, the Energy Efficiency Council have recently launched an Energy Efficiency Certification scheme for professionals who have experience working on energy efficiency retrofits for commercial buildings. However, it does not specifically test energy modelling ability and understanding. NABERS and Green Star also have accreditation systems; again, both do not certify the ability to use BPS accurately. Without a unifying accreditation, professionals need numerous certifications for different schemes, with associated costs. Until a robust BPS accreditation scheme is developed, and included as a standard requirement for energy modelling contracts, particular government initiatives, industry concerns (AIRAH, 2013) are that certification will simply represent an additional cost.

Many of the issue identified as problematic in the use of BPS for existing building retrofitting also exist in the design of new buildings. For existing buildings, it is theoretically possible to know all uncertain inputs, and understand the range of all variable inputs. However, as demonstrated above, it is not practically possible to access the information. For new builds, many inputs will necessarily be unknown, particularly relating to building occupancy. As such, the accuracy of a model is reliant on the user's ability to make reasonable assumptions, and the building being constructed and operated in accordance with the design. It is also likely that peer-review of a new building model would encounter the same difficulties raised above. However, the cost barrier would likely not be as problematic for new buildings, as the magnitude of the project budget would make the relative cost of a BPS engagement less significant.

CONCLUSION

This paper characterised current practice in the Australian commercial building energy retrofitting industry through the analysis of 12 semi-structured interviews with key consultants working in the field. Several key themes have been identified from the interview analysis. A revised systematic approach to building energy retrofitting was proposed, refined from Ma *et al.* (2012) and incorporating the interviewee's experiences and insights. The tension between commercial pressures and BPS accuracy was explored, and the issues leading to uncertainty in BPS predictions were studied.

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